

The Luminosity-Diameter Relations for Globular Clusters and Dwarf Spheroidal Galaxies

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ABSTRACT

It is shown that globular clusters and the dwarf spheroidal companions of the Galaxy have a different distribution of flattening values and appear to occupy adjacent regions of the M_v versus $\log R_h$ plane that can be separated by what will be referred to as the Shapley line. Surprisingly, typical dwarf spheroidal companions to the Milky Way System are fainter than the average Galactic globular cluster.

Key words: globular clusters: general-galaxies: dwarf

1 INTRODUCTION

In 1914 Harlow Shapley started his systematic survey of Galactic globular clusters using the 60-in telescope on Mt. Wilson. The main finding of this study (Shapley 1918ab) was that the Milky Way System is embedded in a vast halo of globular clusters which is centered in the direction of Sagittarius. Two decades later Shapley's (1938ab) discovery the Sculptor and Fornax dwarf spheroidal galaxies on plates obtained with the Bruce Telescope at the Boyden Station of the Harvard Observatory. Shapley characterized these newly discovered objects as star clusters of galactic dimensions. This discovery was the first step in a lengthy exploration that eventually led to the conclusion that the Galaxy is embedded in a corona of such dwarf spheroidal galaxies. The exact relationship between these two classes of Galactic satellites remains a mystery. As Shapley (1943) wrote: "Two hazy patches [the Sculptor and Fornax dwarfs] on a photograph have put us in a fog." It is the purpose of the present *letter* to try to make a small contribution to a deeper understanding of the nature of the globular cluster halo, and of the corona of dwarf spheroidal galaxies, in which our Milky Way System is embedded.

2 DATA ON DWARF SPHEROIDALS

Figure 1 shows a plot of the distribution of the absolute magnitudes M_v of Galactic globular clusters and of the presently known dwarf spheroidal companions to the Milky Way System (see Table 1) as a function of their half-light radii. All data for the globular clusters were drawn

from the recent compilation by Mackey & van den Bergh (2005). The information on the brightest nearby dwarf spheroidals was taken from van den Bergh (2000), and data for the fainter nearby dwarf spheroidals was drawn from Martin et al. (2008). The Sagittarius dwarf galaxy was excluded from Table 1 because both its present luminosity, and its half-light radius, have probably been affected by Galactic tides. It should be stressed that the determinations of the ellipticities of the faintest dwarf spheroidal galaxies listed in Table 1 may suffer from significant stochastic noise. In Figure 1 the Galactic globular clusters are plotted as filled red dots, whereas the dwarf spheroidal companions to the Galaxy are shown as filled blue squares. To guide the eye the globular clusters and the dwarf spheroidal galaxies in Figure 1 have been separated by the line

$$M_v = 16.2 - 14.26 \log R_h. \quad (1)$$

This relation will subsequently be referred to as the Shapley line. The faintest dwarf spheroidals plotted in Figure 1 have such a small stellar population that they do not contain a single red giant star. Some of these objects might actually have fallen slightly above (or the left) of the Shapley line if they had, per chance, harbored a single red giant star. Nevertheless, with all of the presently available data, Eqn. (1) provides a slightly more complete way of describing the data than does the Belokurov et al. (2007) statement "that there is a paucity of objects with half-light radii between ~ 40 and ~ 100 pc." Furthermore, it should be emphasized that the assignment of some of the faintest objects to the dwarf spheroidal class remains provisional until radial velocity information becomes available for a significant number of system members. Information on the globular clusters, which are located

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above and to the left of the Shapley line is believed to be almost complete. On the other hand the data for dwarf spheroidal galaxies become ever more incomplete as one moves towards the lower right hand corner of Figure 1. It is expected that many large, faint (and hence low surface brightness) dwarf spheroidals remain to be discovered. It is noted in passing that the four extended luminous clusters that have recently been discovered in the halo of M31 have M_v and R_h values (Mackey et al. 2006) that place all of these objects to the left of the Shapley line, i.e. in the globular cluster domain. The recently discovered old extended object M33-EC1 also falls to the left of the Shapley line, i.e. in the globular cluster domain.

3 DISCUSSION

Shapley (1938b) wrote: “If intermediate forms connecting them [i.e. Sculptor and Fornax] with one of these standard types were found, a correct interpretation would be facilitated.” The data plotted in Figure 1 suggest that, at least in the Milky Way System, such intermediate-type objects are lacking. The most striking difference between globular clusters and dwarf spheroidal galaxies is that the diameters of the latter are typically one or two orders of magnitude larger than those of the former. A second difference revealed by Figure 1 is that the known dwarf spheroidals are spread out over a range of 10^5 in luminosity, whereas the luminosity distribution of globular clusters is strongly peaked at $M_v \simeq -7.5$. A Kolmogorov-Smirnov test shows that there is only an 8% probability that the observed luminosities of globular clusters and of dwarf spheroidals were drawn from the same parent population. The existing sample of dwarf spheroidal companions to the Galaxy is almost certainly incomplete in the lower right hand corner of Figure 1. Future discoveries are therefore expected to reduce the probability that dwarf spheroidals and globular clusters were drawn from the same parent population. It is of interest to note that the median luminosity of the known dwarf spheroidal galaxies in Table 1 is $M_v^* \sim -6.5$, whereas the median luminosity of Galactic globular clusters is $M_v^* \sim -7.5$. In other words typical dwarf spheroidal *galaxies* are fainter than the average globular *cluster*. This difference is likely to increase as more very faint and low surface brightness dwarf spheroidal companions to the Galaxy are discovered. At least part of this difference is, no doubt, due to the fact that many low-mass globular clusters were destroyed by stellar-dynamical evaporation (McLaughlin & Fall 2008). Since the mass loss rate $-dM/dt \propto R_h^{-3/2}$, such mass loss will affect compact clusters much more than extended dwarf spheroidals. In other words, one cannot yet exclude the possibility that dwarf spheroidals and globular clusters might initially have formed with similar luminosity distributions. The conclusion that typical dwarf spheroidal galaxies are quite faint, and therefore difficult to observe, fits very comfortably into the framework of a hierarchical clustering scenario in which massive galaxies, such as the Milky Way System, should be surrounded by large numbers of satellite dark matter dominated halos (Kaufmann, White & Guideroni (1993), Klypin et al. (1999), Moore et al. (1999).

Data on the normalized distribution of flattening values for the 100 globular clusters (van den Bergh 2008) that lie above and to the left of the Shapley line, and for the 21 dwarf spheroidals (Martin et al. 2008) that are situated below and to the right of the Shapley line are listed in Table 2 and plotted in Figure 2. This figure shows that the objects below the Shapley line are significantly more flattened than are those that lie above it. A

Kolmogorov-Smirnov test shows that there is a $< 0.01\%$ probability that these globular clusters and dwarf spheroidal galaxies were drawn from the same parent population of flattening values. The reason(s) for this difference are not yet fully understood. Rotation would suggest implausibly small internal velocity distributions and tidal deformation would require very eccentric orbits for some dwarf spheroidal companions to the Galaxy. Alternatively the high observed flattening of the dwarf spheroidal galaxies might perhaps be due to the fact that they are embedded in tri-axial dark matter mini halos. The existence of such dark matter halos might also contribute to the fact that the stars in dwarf spheroidals appear to exhibit both a greater age spread, and a larger range in metallicities, than do those in most globular clusters.

4 CONCLUSIONS

The Milky Way system is embedded in a halo of globular clusters and in a more extended corona of dwarf spheroidal galaxies. These two classes of objects show a highly significant difference in their average flattenings, with dwarf spheroidals being more elongated than globular clusters. Furthermore dwarf spheroidal companions to the galaxy and galactic globular clusters are located in distinct regions of the M_v versus $\log R_h$ diagram. Available data allow one to draw a line (the Shapley line) that separates Galactic globular clusters from presently known dwarf spheroidal galaxies. The extended luminous globular clusters in M31 and M33 fall inside the same domain as do Galactic globular clusters. It is also pointed out that the median luminosity of the dwarf spheroidal companions to the Galaxy is lower than that of globular clusters. Still undiscovered dwarf spheroidal companions to the Galaxy are expected to be both larger and fainter than those which are already known. New discoveries are therefore expected to widen the gap between the median luminosities of globular *clusters* and dwarf spheroidal *galaxies*. In other words dwarf spheroidal *galaxies* are, on average, significantly fainter than typical globular star *clusters*. I am indebted to Giuseppe Bertin for a discussion of the properties of globular clusters and to Bonnie Bullock, Brenda Parrish and Jason Shrivell for technical assistance. Also, I would like to thank a particularly helpful referee who emphasized how the positions of the faintest objects in Figure 1 might be affected by the presence of a single red giant star.

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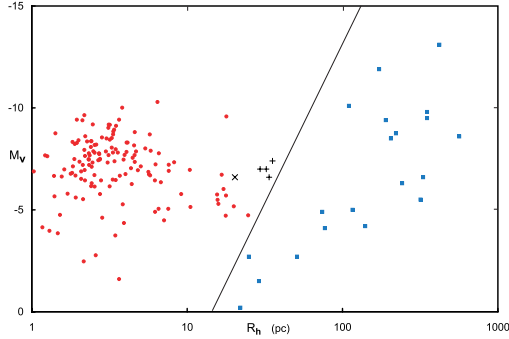


Figure 1. The figure shows a clear-cut separation between the distribution of Galactic globular clusters (filled red circles) and dwarf spheroidal companions to the Galaxy (filled blue squares). A line separating these two types of objects is given by Eqn. (1). The data are most incomplete in the lower right-hand corner of the diagram, i.e. for the faintest and largest objects. Note the striking difference between the luminosity distributions of globular clusters and dwarf spheroidal galaxies. Four luminous extended globular clusters in the outskirts of M31 (Mackey et al. 2006) are shown as plus signs. The extended cluster M33-EC1 is plotted as a cross.

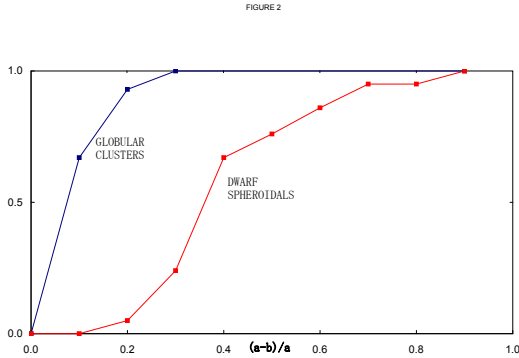


Figure 2. Normalized frequency distribution of flattening values for objects situated above and to the left of the Shapley line (globular clusters) and for those situated to the right and below this line (dwarf spheroidal galaxies). The figure shows that dwarf spheroidal galaxies are, on average, much more flattened than are globular clusters.

Table 1. Data for nearby dwarf spheroidals

Name	ε	M_v	R_h (pc)
Boo I	0.39	-6.3	242
Boo II	0.21	-2.7	51
CVn I	0.39	-8.6	564
CVn II	0.52	-4.9	74
Car	0.33	-9.4	190
Com	0.38	-4.1	77
Dra	0.31	-8.75	221
For	0.30	-13.1	420
Her	0.68	-6.6	330
Leo I	0.21	-11.9	172
Leo II	0.13	-10.1	110
Leo IV	0.22	-5.0	116
Leo T	0.29	...	178
Scl	0.35	-9.8	350
Seg 1	0.48	-1.5	29
Sex	0.35	-9.5	350
UMa I	0.80	-5.5	318
UMa II	0.63	-4.2	140
UMi	0.50	-8.5	205
Wil 1	0.47	-2.7	25
S1058	0.38	-0.2	22

Table 2. Normalized frequency distribution of flattening distributions for Galactic globular clusters and dwarf spheroidal companions to the Galaxy

(a-b)/a	globular clusters	dwarf spheroidal galaxies
0.00	0.00	0.00
0.10	0.67	0.00
0.20	0.93	0.05
0.30	1.00	0.24
0.40	1.00	0.67
0.50	1.00	0.76
0.60	1.00	0.86
0.70	1.00	0.95
0.80	1.00	0.95
0.90	1.00	1.00

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